Earthquake History of the Southern Hayward Fault, San Francisco Bay Area, California

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Investigations Undertaken

The purpose of this initial paleoseismic study of the southern Hayward fault is to better constrain the timing of late Holocene surface-rupturing earthquakes along the southern Hayward fault. Understanding the timing of large paleoearthquakes on the Hayward fault is critical for assessing seismic hazards and calculating probabilities of large earthquakes in the populated San Francisco Bay area. The southern segment of the Hayward fault is a major contributor to seismic hazard in the southern Bay area, and there is a clear need to improve our characterization of the fault. An improved understanding of the earthquake cycle on the southern Hayward fault is critical for providing input to probability estimates for future earthquake occurrence, and thus for developing adequate risk mitigation in the San Francisco Bay area.

We conducted field and air-photo reconnaissance of the entire southern Hayward fault, and identified nineteen potential sites that could provide information on the timing of past earthquakes on the fault. Our approach was to progressively assess the viability of several potential sites, and then target sites that would yield the best-constrained data on earthquake history. Through this program of increasingly focused studies, we targeted seven of the nineteen sites for detailed field mapping and/or subsurface exploration. Field mapping at the Mt. Calvary Cemetery, Holy Sepulchre Cemetery, and DeLucchi Property showed that these sites may yield good paleoseismologic data, but did not hold, in our judgement, as much potential as the Union Array, Oakland Zoo, Nakata Nursery, and Shinn Historic Park sites. We conducted subsurface borings at the Union Array and Nakata Nursery sites in order to evaluate subsurface stratigraphy, and observed that massive fine-grained sediments underlie both of these sites. We excavated trenches at the Shinn Historic Park, Oakland Zoo, and Union Array sites to evaluate stratigraphic and structural relations across a zone that experienced surface deformation during the 1868 earthquake. Ages of stratigraphic units exposed in the trenches at the Shinn Park and Union Array sites were estimated on the basis of radiocarbon analyses on charcoal fragments.

Results

The 52-km-long southern Hayward fault contains very few viable sites for obtaining paleoseismologic data (Table 1). Much of the fault is covered by urban development, and most good investigative sites have been modified or destroyed as a result of this urbanization. We conclude that there may be only a few viable sites that may provide well-constrained information on the timing of past earthquakes. In addition, there are few or no sites along the fault that are known to hold the potential for providing additional data on long-term fault slip rate. We recommend a series of exploratory test trenches at several sites along the fault (Table 1), in order to identify the presence or absence of any additional viable sites.

Our results from the Shinn Historic Park have been provided in a previous NEHRP Annual Summary and a NEHRP Final Technical Report (Kelson, 1999; Kelson et al., 2000). Shinn Historic Park is on a small topographic high on the western side of the main fault strand (Figure 2). This high is developed on Holocene alluvium deposited by the west-flowing Alameda Creek (presently about 0.8 km northwest of the site), and is bordered by an east-facing scarp that is about 0.5 to 0.6 m high. The near-surface alluvium is part of the Niles alluvial fan, which was deposited during intermittent large floods along Alameda Creek. On the basis of deformed late Holocene alluvial stratigraphy exposed in the trench, we conclude that the 1868 surface rupture produced monoclinal warping of the ground surface, rather than brittle fault displacement. In addition, there is geologic evidence of additional warping events within the past approximately 1,300 years at the Shinn Historic Park. We interpret the possibility of a total of four earthquakes (including the 1868 rupture) since this time. Each of these possible events appears to have produced roughly 30 cm (± 20 cm) of vertical separation at the site. This separation is consistent with historical accounts of the 1868 earthquake at the Shinn site, which indicate that the eastern side of the fault dropped about 30 cm. Based on the eighteen radiocarbon age estimates, the trench exposure yielded the following possible times for late Holocene surface deformations: between AD 540 and AD 780, between AD 680 and AD 890, between AD 680 to AD 1868, and in AD 1868.

In addition, we excavated and logged a 15-m-long trench across the Hayward fault at the Oakland Zoo site, near the entrance to Knowland Park (Table 1; Kelson et al., 2000). Evidence of fault creep at the site and in the general vicinity includes offset curbs, pipeline damage, and deformation of creep-monitoring devices (Lienkaemper, 1992). Based on measurements from a creep-monitoring device at the zoo entrance, the aseismic creep rate is episodic and averages 4 to 5 mm/yr (J. Leinkaemper, USGS, personal communication, 2000). Our air-photo and field reconnaissance shows that the active creeping trace crosses Holocene colluvial and alluvial sediments within the Arroyo Viejo valley (Kelson et al., 2000). Our trench exposed serpentine bedrock on the northeast in fault contact with Holocene colluvial deposits on the southwest. Historic artificial fill overlies both of these geologic units, and, based on historic documents and air photos, probably was placed in the 1920s or 1930s. Because the ground surface was cut prior to placement of the fill, the uppermost stratigraphic record at the site has been removed. Thus, this trench provides little information on the timing of the most-recent surface rupture along the southern Hayward fault.

Lastly, we excavated and logged a 40-m-long trench across the eastern strand of the Hayward fault at the Union Array site in Union City (Table 1; Kelson et al., 2000). This site contains a nearly closed depression that has trapped sediments along the eastern strand of the Hayward fault. Fine-grained alluvium has been deposited in the depression, and overlies the eastern fault strand. Prior to trenching, we believed that the late Holocene “ponded alluvium” deposits along the eastern strand would provide an opportunity to assess the timing of paleoearthquakes along the southern Hayward fault. The 6-m-deep trench exposed massive silty clay laid down in the depression via slopewash processes. This silty clay overlies sandstone bedrock in the western

part of the trench. A moderately developed soil has formed in the colluvial deposits, and is characterized by a 75-cm-thick Btb soil horizon and a moderate level of secondary (pedogenic) calcium carbonate accumulation. However, a single radiocarbon date from the base of the colluvial deposits suggests a calibrated age of approximately 9 ka for the deposits exposed at the base of the trench (CAMS#68977/68978; G. Seitz, LLNL, personal communication, 2000). No fault was encountered in the bedrock or surficial deposits. On the basis of these relations, we interpret that the eastern strand of the Hayward fault at this site has not experienced surface rupture within the past several thousand years, and that the western, creeping strand ruptured during the 1868 and earlier earthquakes.

Non-technical Summary

Understanding the timing of large paleoearthquakes on the Hayward fault is critical for assessing seismic hazards in the populated San Francisco Bay area. In this study, we identified and evaluated 19 possible sites that could provide information on the timing and recurrence of past earthquakes along the southern Hayward fault. At one site in Fremont, preliminary data suggest the occurrence of four surface deformational events at the site since about AD 540, including the earthquake in AD 1868. Excavations at two other sites did not yield adequate information for evaluating the timing of past earthquakes on the fault.

Reports Published

Kelson, K.I., 1999, Earthquake history of the southern Hayward fault: Annual Summary Report submitted to the USGS National Earthquake Hazard Reduction Program, Award # 99-HQ-GR-0102, 4 p.

Kelson, K.I., Lettis, W.R., and Baldwin, J.N., 2000, Earthquake history of the southern Hayward fault: unpublished report submitted to the USGS National Earthquake Hazard Reduction Program, Award # 99-HQ-GR-0102, 23 p.

Data Availability

Copies of the trench logs and boreholes data are available from the authors, at the address listed above.

Table 1. List of potential paleoseismologic sites considered for detailed investigation during this study. Sites listed from north to south.

Site	City	Location* (km)	Stratigraphic Target	Rating**	Investigations Completed*** PGI	APR	FR	HAB	ET	Comments / Recommended Future Action
Mills College	Oakland	29.5	Alluvium and scarp-derived colluvium	2	x	x	x			Colluvial material shed off uphill-facing scarp. Exploratory trenching across scarp, colluvium and alluvium possible.
82nd Avenue	Oakland	32.3	Scarp-derived colluvium	5	x	x	x			Colluvial material shed off uphill-facing scarp. Recommend exploratory trenching across scarp and colluvium.
Oakland Zoo Entrance	Oakland	33.7	Alluvium	8	x	x	x		x	Alluvium deposited by Arroyo Viejo; nearby creepmeter. Recommend exploratory trenching across alluviated surface.
Dunsmuir Estate	Oakland	35.0	Alluvium	4	x	x	x			Colluvial material shed off downhill-facing scarp. Culturally modified. Permission unlikely. No action recommended.
Lake Chabot Access Road	San Leandro	37.1	Scarp-derived colluvium	4	x	x	x			Colluvial material shed off uphill-facing scarp. Recommend exploratory trenching across scarp and colluvium.
Mt. Calvary Cemetery	San Leandro	38.0	Alluvium	7	x	x	x			Documented faulting of alluvium. Re-excavate previous exploratory trench across alluvium.
Rufus Court	Hayward	43.1	Alluvium	2	x	x	x			Urbanized. No action recommended.
Hayward Old City Hall	Hayward	44.6	Alluvium	1	x	x	x			Subsequent trench by consultant showed lack of bedded stratigraphy. No action recommended.
Hayward Plunge Park	Hayward	45.3	Alluvium	6	x	x	x			Urban park setting. Creep documented at site. Recommend exploratory trenching possible if permission could be obtained.
Holy Sepulchre Cemetery	Hayward	48.0	Alluvial-fan and colluvial deposits	6	x	x	x			Recommend exploratory trenching across back-edge of side hill bench and at base of scarp.
May Road	Union City	53.7	Hillslope colluvium	6	x	x	x		x	No action recommended
Union Array	Union City	54.3	Ponded alluvium	7	x	x	x	x	x	No action recommended
DeLucchi Property	Fremont	56.3	Alluvial-fan deposits and alluvium	8	x	x	x			Site to be developed soon. Permission request denied. Recommend pursuing permission for exploratory trenching south of unnamed creek.
Nakata Nursery	Fremont	57.6	Alluvium	6	x	x	x	x		Massive fine-grained deposits in borehole, but local coarse deposits possible. Recommend exploratory trench along southern border.
US Gypsum Plant	Fremont	58.8	Alluvium	3	x	x	x			Possible coarse alluvium deposited by Alameda Cr. Creep documented at site. Permission request denied. No action recommended.
Shinn Historic Park	Fremont	59.1	Alluvium, Historic deposits	8	x	x	x		x	No action recommended.
Tule Pond	Fremont	60.4	Ponded alluvium	9	x	x	x			Site investigated under BAPEX, contemporaneously with this study. USGS conducted additional investigations in summer and fall 2000.
Gallegos Winery	Fremont	63.5	Scarp-derived colluvium	3	x	x	x			Fault location only moderately well constrained. No action recommended.
Sands Property	Fremont	65.5	Ponded alluvium	5	x	x	x			Colluvial material shed off uphill-facing scarp. Recommend exploratory trenching across east-facing scarp and ponded alluvium. Under consideration for development.

*Site location based on distance along fault from Point Pinole, as shown by Lienkaemper (1992).
**Qualitative rating (scale of 1 to 10) based on site geologic conditions, likelihood of obtaining paleoseismologic data, and likelihood of obtaining permission to conduct exploratory investigations.
***PGI: Photo Geologic Interpretation; APR: Analysis of Previous Reports; FR: Field Reconnaissance; HAB: Hand-auger Boring; ET: Exploratory Trenching